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Research Article

The first national assessment of established non-native species in Türkiye

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Abstract

The ecological and socio-economic impacts of non-native species underscore the importance of maintaining accurate national lists to support biosecurity and management strategies. Türkiye's most recent national list highlights ongoing challenges in keeping records up-to-date. To advance Türkiye's national assessment of non-native species, we present the first comprehensive list of established non-native species, documenting 271 species from 160 families across diverse taxonomic groups. Marine species (n = 198) dominated the list, with notable contributions from Chordata, Mollusca, and Arthropoda, followed by Terrestrial (42), Freshwater (27), Terrestrial/Freshwater (3) and Freshwater/Marine (1). Our spatial analysis revealed considerable regional variation in data availability, with urban and coastal areas exhibiting higher rates of species establishment, likely facilitated by human-mediated pathways. We also identify Türkiye's role as a crucial hub for the spread of non-native species across country borders. Furthermore, we demonstrate that 17% of non-native species have known ecological or economic impacts, emphasizing the need for targeted impact assessments, monitoring, and proactive management. By providing a detailed and up-to-date inventory of established non-native species and their impacts, this study offers a critical foundation for strengthening biosecurity policies, guiding targeted monitoring efforts, and fostering coordinated management responses at local, national, and international scales to safeguard Türkiye's biodiversity.

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Introduction

The introduction of non-native species – i.e. those transported beyond their natural biogeographic range as a consequence of human actions – poses massive ecological threats to biodiversity, and their socio-economic impacts represent not only a burden on national economies but are also detrimental to human well-being (Cucherousset and Olden 2011; Diagne et al. 2020). In this scenario, identifying and assessing non-native species at the national level is essential for their effective management in view of legislation measures (Haubrock et al. 2025; Soto et al. 2025). National non-native species lists serve multiple purposes: (i) they compile species seen as relevant in terms of their potential or existing threats, (ii) they help prioritize species for management actions, and (iii) they inform biosecurity measures by identifying those species that may threaten neighboring countries through trade and travel (Hulme 2009).

However, these national lists, whenever available, are frequently inconsistent and neglect the inherent differences among populations within countries, reflecting the subjective biases of assessors and differences in research fields (e.g. aquatic vs terrestrial, animals vs plants), the status of non-native species (i.e. whether they are introduced, established, or invasive: *sensu* Soto et al. 2024a), and the criteria for determining a species as 'invasive' (i.e. spread vs impact: (Cuthbert et al. 2022; Vilizzi et al. 2022a; Haubrock et al. 2024; Soto et al. 2024b). Following Soto et al. (2024a), non-native species are those transported beyond their native range by humans, established non-native species are those with self-sustaining populations in the wild, and invasive non-native species are established non-native species that are in the process of spreading, as spread potential mitigates the number of opportunities and experienced conditions that may modulate exerted impacts. Inconsistent application of terminology and the use of varying criteria for invasive terminology have resulted in the misclassification of non-native species, with some being listed as established without clear evidence, and some being flagged as invasive without properly justifying how invasive terminology was assessed or qualified (see Soto et al. 2024a) – although we acknowledge that drawing a line to distinguish the different statuses of non-native species can be obscure.

Several national lists of non-native species have emerged over the past two decades, providing essential tools for guiding the management of non-native species, with most European Union member states having compiled such lists even before formal regulations were implemented (Genovesi and Monaco 2013; Cerri et al. 2022). Türkiye, however, exemplifies the numerous challenges associated with the maintenance of accurate (and frequently updated) national lists. Given the country's significant economic position (ranked 18th globally: IMF 2025), coupled with its rich biodiversity (Şekercioğlu et al. 2011) and strategic location at the intersection of the Middle East and Europe (Kahraman et al. 2012), such a national list is urgently needed to mitigate the impacts of biological invasions. This is because non-native species in Türkiye have been shown to pose substantial ecological and economic threats, adversely affecting various sectors including agriculture, fisheries, tourism, and human health (Tarkan et al. 2012, 2024b). Their

economic impact, while significant, is often underrepresented in national financial assessments, despite the costs they impose on food production, biodiversity, and public infrastructure (Shackelford et al. 2013; Bălăcenoiu et al. 2023). Incorporating these costs into environmental policy and fiscal planning – such as through 'green budgeting' – could improve resource allocation and support more proactive management responses. Additionally, given Türkiye's trade routes and the high volume of international travel, the risk of new non-native species introductions in the country remains high (Kahraman and Altun 2016).

Although the first and only national list of non-native species in Türkiye dates back to 2020 and includes 872 species (Uludag et al. 2020), questions remain about its accuracy and utility. This is predominantly as the list includes all recorded occurrences of non-native species regardless of their establishment status rather than focusing solely on those non-native species with self-sustaining populations, i.e. established non-native species (hereafter, 'established species'; *sensu* Soto et al. 2024a). It is therefore crucial to differentiate between those non-native species that are introduced but not established, as their impact and spread potential remains questionable, and those non-native species that are established, because they are therefore likely to pose an immediate threat (Haubrock et al. 2026a, b).

Updating existing national lists to guide future monitoring is essential for developing effective early-warning systems and intervention strategies. To fill this gap, this study aims to provide a first comprehensive overview (i.e. dataset) of established non-native species in Türkiye. By analyzing the composition of these species, we seek to understand the patterns and implications of their establishment in Türkiye. We hypothesize that (1) the composition of established species will be dominated by terrestrial plants and marine invertebrates, reflecting patterns observed in comparable regions, and (2) regions within Türkiye with higher human activity, particularly those with dense populations, significant trade and transportation infrastructure, and intensive land use, will exhibit higher rates of non-native species establishment. In contrast, we hypothesize that (3) regions with less human activity or more remote locations, such as certain inland or mountainous areas, will show lower rates of invasion due to reduced opportunities for species introduction and less disturbance to native ecosystems. We also anticipate that (4) known ecological and economic impacts of these established non-native species are highly biased towards well-known and well-studied invaders and taxonomic groups. Finally, this study aims to assess known invasion impacts and, whenever possible, the level of risk posed by the established species in Türkiye so as to provide targeted recommendations for management and control.

Material and methods

Data compilation

To compile a comprehensive and up-to-date dataset of established non-native species in Türkiye, we used the recent global database of established non-native species occurrences by Briski et al. (2024). This database gathered information from several sources, including the online database "Standardising and Integrating Alien Species" (SInAS: Seebens 2021) and national lists on non-native species (see Briski et al. 2024 and Haubrock et al. 2025). In the SInAS database, species classified as CASUAL or ABSENT in the 'degreeOfEstablishment' and 'occurrenceStatus' columns were ex-

cluded, as these categories indicate non-established populations (Groom et al. 2019), whereas species with undetermined (blank) establishment status were retained and treated as established based on supporting evidence from expert assessments and the literature. We emphasize that our dataset also contains taxonomically accepted subspecies as per the "Global Biodiversity Information Facility" (GBIF: https://www.gbif.org/). When a species was not found in GBIF, a manual search was conducted to verify its scientific name by consulting the "World Register of Marine Species" (WoRMS: https://www.marinespecies.org/), coupled with a general internet search in September 2024 (Briski et al. 2024). This process yielded a total of 1,092 non-native species in Türkiye. After a comprehensive review of each taxonomic group by Turkish experts (Suppl. material 1), based on the most up-to-date literature, native, cryptogenic and non-established non-native species were filtered out and a total of 271 non-native species (≈ 25%) remained classified as established in Türkiye.

Habitat and native range

For every species reported in the dataset, we identified the habitat it predominantly occupies (i.e. terrestrial, freshwater, marine, or a mixture thereof) by consulting the Step2_StandardTerms_GRIIS file (Seebens 2021), which contains habitat data originating from the "Global Register of Introduced and Invasive Species" (GRIIS; Pagad et al. 2018). We then assigned one or more habitats (i.e. a combination of them, such as freshwater-marine) to each species. Where habitat information was not available, we conducted an additional manual search of WoRMS and a general internet search between July and September 2024. Notably, brackish habitats were defined as marine based on the Venice System (1958); see Table 1.

We extracted the native range of each established species in Türkiye in two ways: (i) by employing the web-scraping technique on several online databases, including "Plants of the World Online" (https://powo.science.kew.org/) and GBIF, and (ii) by consulting targeted publications. We identified the native range at the biogeographic realm (i.e. Nearctic, Neotropical, Palaearctic, Afrotropical, Indo-Malayan, Australasian, and Oceanian). Due to the low number of species from the Oceanian realm, these were combined with those from the Australasian realm. Species associated with two realms of equal weight were assigned to each realm (i.e. the taxon was distributed in both realms). Species distribution across two or more realms (i.e. cosmopolitan) and species with unclear native range were not considered in the analyses.

Distribution of established species in Türkiye

To unveil the spatial pattern of established non-native species, we extracted GBIF occurrences for each of them in Türkiye. We restricted downloads to only those

Table 1. Breakdown of non-native organism habitat classifications (after Haubrock et al. 2025).

Habitat	Description
Freshwater	Species classified as freshwater inhabit environments such as rivers, lakes, and streams, with salinity < 0.5 g kg^{-1}.
Marine	Species classified as marine inhabit environments such as oceans, seas, coastal areas, and estuaries with a salinity level ≥ 0.5 g kg^{-1}.
Terrestrial	Species classified as terrestrial are found on land, including habitats such as forests, grasslands, deserts, and urban areas.
Semi-aquatic	Species associated with both terrestrial and aquatic habitats (e.g. freshwater-terrestrial), depend on both aquatic and terrestrial habitats to complete their life cycle or daily activities.

occurrences categorized as 'present', with coordinates that did not have geospatial issues, and removed fossil records. The download was done by using the *occ_download* function from the *rgbif* R package (Chamberlain et al. 2017; GBIF.org 2025). To identify the number of established non-native species in each administrative region (i.e. referring to geographical areas into which Türkiye is divided, that is *İller* [Provinces] for terrestrial regions and Exclusive Economic Zones (EEZs) for marine regions), we overlapped the established non-native richness within the boundaries of each administrative area, including marine areas. We downloaded administrative terrestrial regions from the *geodata* R package (Hijmans et al. 2024), while marine areas (Exclusive Economic Zones) were extracted from "Marine Regions" (https://marineregions.org/: Flanders Marine Institute 2023).

Compilation of impact and risk of invasiveness

For each established non-native species, we extracted all available information on its reported economic, environmental and social impacts from GRIS at two levels: (i) reported in Türkiye and (ii) reported globally outside of Türkiye. In the case of established non-native species with reported impact in Türkiye, we checked the "Centre for Agriculture and Biosciences International" (CABI: https://www.cabi.org/) and the *InvaCost* database (v4.1: Diagne et al. 2020) for information on the type of impact. If the data were not available in CABI or *InvaCost*, we used Google Scholar to search for the information using the following search string: "species scientific name" and "impact" or "invasive" in order to broaden the search, especially for less-studied species. Google Scholar was used solely to verify whether any peer-reviewed evidence of impacts existed. This search did not result in reclassification of impacts, and species without documented impacts remained classified as such. Comparison between regional (Türkiye) and global scale allowed us to identify potential gaps in impact reporting.

For those established non-native species for which published information was available on the level of risk posed in risk assessment areas across Türkiye (including the country as a whole), we included screening data from studies using the Aquatic Species Invasiveness Screening Kit (AS-ISK: Copp et al. 2016; Vilizzi et al. 2025). The AS-ISK (available in its v2.4.1 at https://tinyurl.com/ISK-toolkits) is a taxon-generic, multilingual decision-support tool that complies with minimum standards for assessing non-native species (Copp et al. 2016, 2021; Vilizzi et al. 2025). It consists of 55 questions, 49 of which are for Basic Risk Assessment (BRA) and six are for Climate Change Assessment (CCA). For each screened species, two scores are obtained: BRA, under current climate conditions, and BRA+CCA, under predicted climate (change) conditions. Scores < 1 suggest a 'low risk' of the species being or becoming invasive in the risk assessment area, whereas scores ≥ 1 indicate a 'medium risk' or a 'high risk', which are distinguished using a calibrated threshold (Vilizzi et al. 2022a). For those species classified as high risk, we also distinguished a 'very high risk' category using an *ad hoc* threshold ≥ 45 see Britton et al. (2011). Identification of very high-risk species helps to prioritize allocation of resources for comprehensive (follow-up) risk assessment (Vilizzi et al. 2022a). In total, there were six AS-ISK applications of relevance to this study (i.e. Bilge et al. 2019; Killi et al. 2020; Tarkan et al. 2021, 2017; Yapici 2021), noting that the screenings by Tarkan et al. (2017) updated the previous ones by Tarkan et al. (2014) using a predecessor toolkit to the AS-ISK.

Results

The final dataset listed 271 established non-native species in Türkiye. These constituted a total of 160 families from 25 classes and 11 phyla (Fig. 1; Suppl. material 1). The Families with the highest number of established non-native species were Formicidae (n = 14), followed by Pyramidellidae (9), Penaeidae (8), Tetraodontidae (7) and Apogonidae (5), with each of the remaining families containing fewer than five species. In terms of Classes, the most species-rich was Actinopterygii (100), followed by Gastropoda (48) and Malacostraca (26). Regarding Phyla, Chordata was the most represented (111 species), followed by Mollusca (67) and Arthropoda (52). The majority of species were strictly marine (198), followed by terrestrial (42) and by those classified as strictly freshwater (27). Only a few species were classified as freshwater-terrestrial (3) and freshwater-marine (1) (Fig. 2).

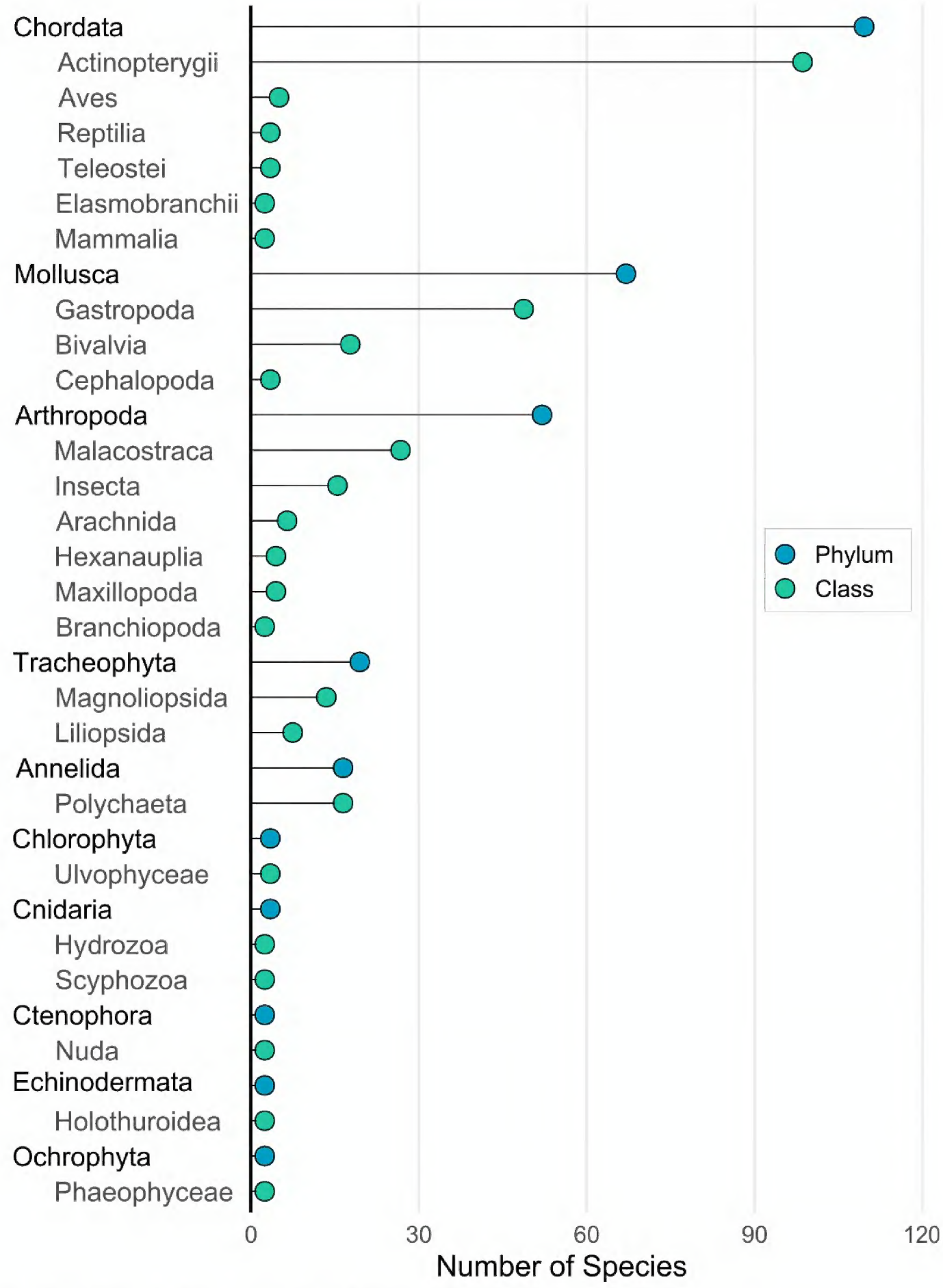

Figure 1. Breakdown of Phyla and Classes with the highest number of established species in Türkiye.

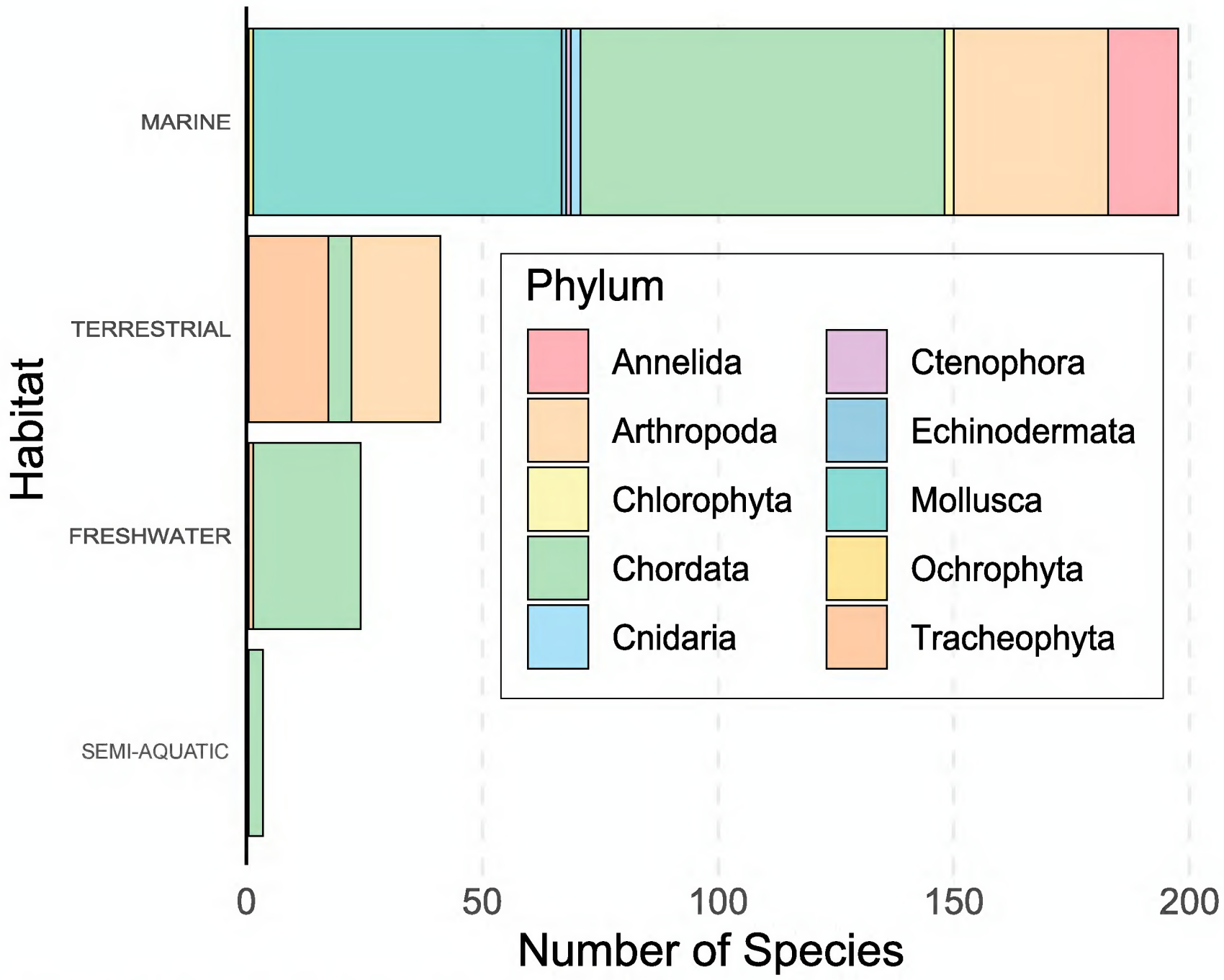

Figure 2. Barplot of established species in Türkiye broken down by habitat.

From GBIF, we gathered a total of 10,301 records for the 271 identified established non-native species in Türkiye. Most of the records came from three bird species, namely the rose-ringed parakeet *Psittacula krameri* (*n* = 5,080; 49.3%), the Alexandrine parakeet *Psittacula eupatria* (2,166; 21.0%), and the common myna *Acridotheres tristis* (879; 8.5%). These species together collectively accounted for a total of 8,125 occurrences (78.8%). We observed a latitude gradient, with most of the species concentrated in the western part of the country and decreasing eastwards. The areas or zones with the highest numbers of reported species were Kayseri and Muğla with 37 established non-native species, followed closely by Antalya with 34 established non-native species (Fig. 3; Suppl. material 2).

We identified the native range for 256 established species in Türkiye (84% of the total). The biogeographic realm where most established species originate was Indo-Malayan (n = 116; 45.3%), with more than twice the number of species in Australasia (n = 52; 20.3%; Fig. 4). Other realms with a lower number of established species were Palearctic (n = 39; 15.2%), Afrotropical (n = 17; 6.6%), Nearctic (n = 16; 6.2%), and Neotropical (n = 6; 2.3%; Fig. 4).

The majority of established non-native species in Türkiye had no reported impacts (*n* = 224; 83%), although this number decreased to 157 (59%) at the global scale. Conversely, the 47 species with reported impacts in Türkiye (17%) increased to 114 (41%) at the global scale. The proportion of established species with documented impacts was generally lower than those without reported impacts, highlighting a considerable gap in impact assessment and reporting across taxa (Fig. 5). Among species with known impacts, ecological and environmental were the most

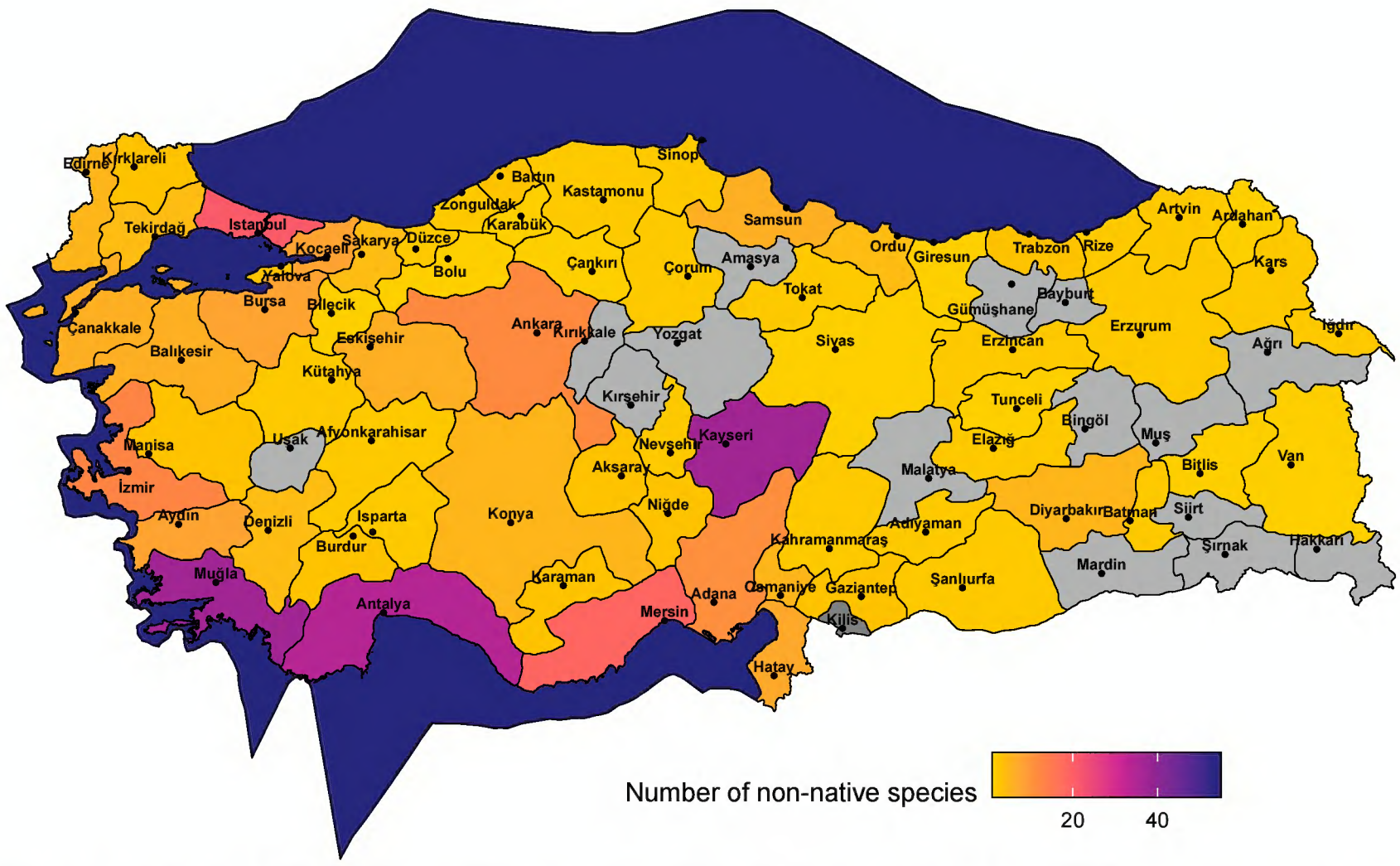

Figure 3. Number of established species in each administrative area of Türkiye based on GBIF records. Gray areas represent administrative areas without non-native species based on GBIF. The marine area represents the Exclusive Economic Zone (extracted from Marine Regions marineregions.org, Flanders Marine Institute 2023).

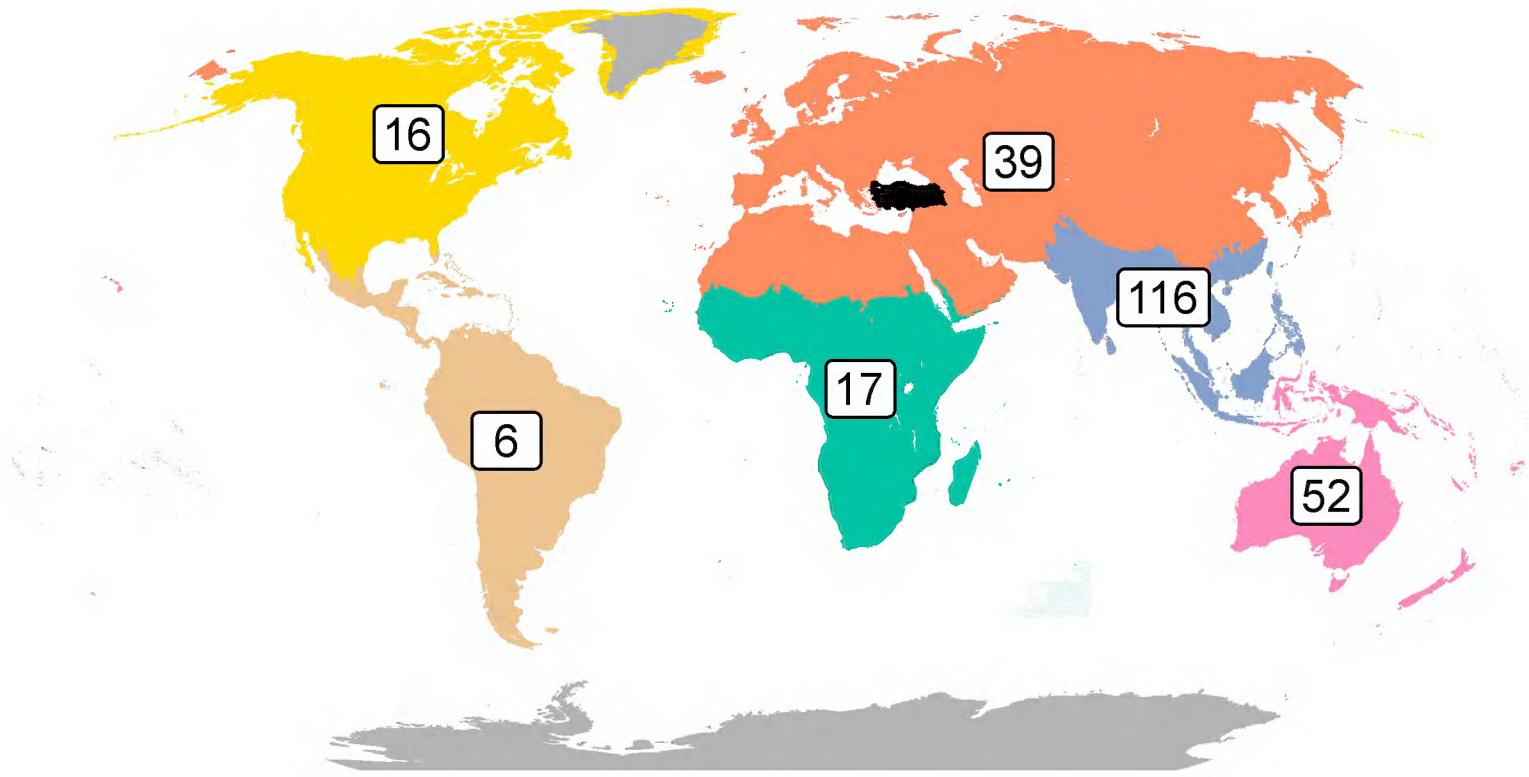

Figure 4. Biogeographic origin of established non-native species in Türkiye (highlighted in black). Numbers represent how many of the established species are native to their regions of origin.

frequently cited (n = 90; 33%), followed by economic (45; 16%) and socio-cultural (28; 11%). Regarding ecological impact mechanisms (Fig. 6), competition was the most commonly reported (63), followed by predation (32) and rapid growth (27). Other recorded mechanisms included habitat alteration, disease transmission, and, among others, resource use, though these were reported less frequently.

The six AS-ISK applications of relevance to this study provided screenings for 62 established species, representing ≈ 23% of the 271 species in total from the list (Suppl. material 2). The risk assessment areas consisted of the inland waters of Türkiye (Tarkan et al. 2017, 2021; Aksu et al. 2024) and of the marine waters of the

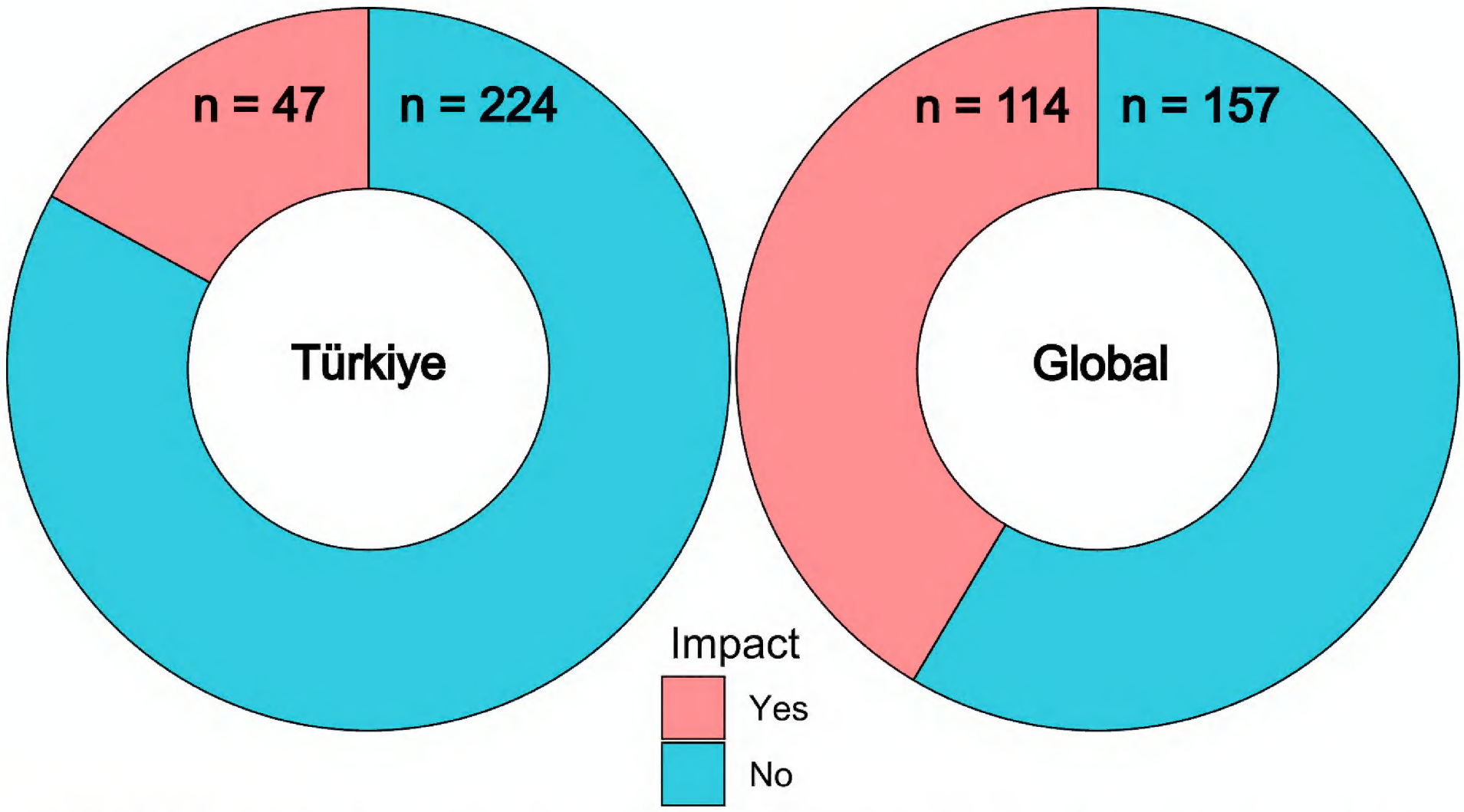

Figure 5. Doughnut plot indicating established species with (red) and without impact (blue) known from Türkiye (a) and (b) globally.

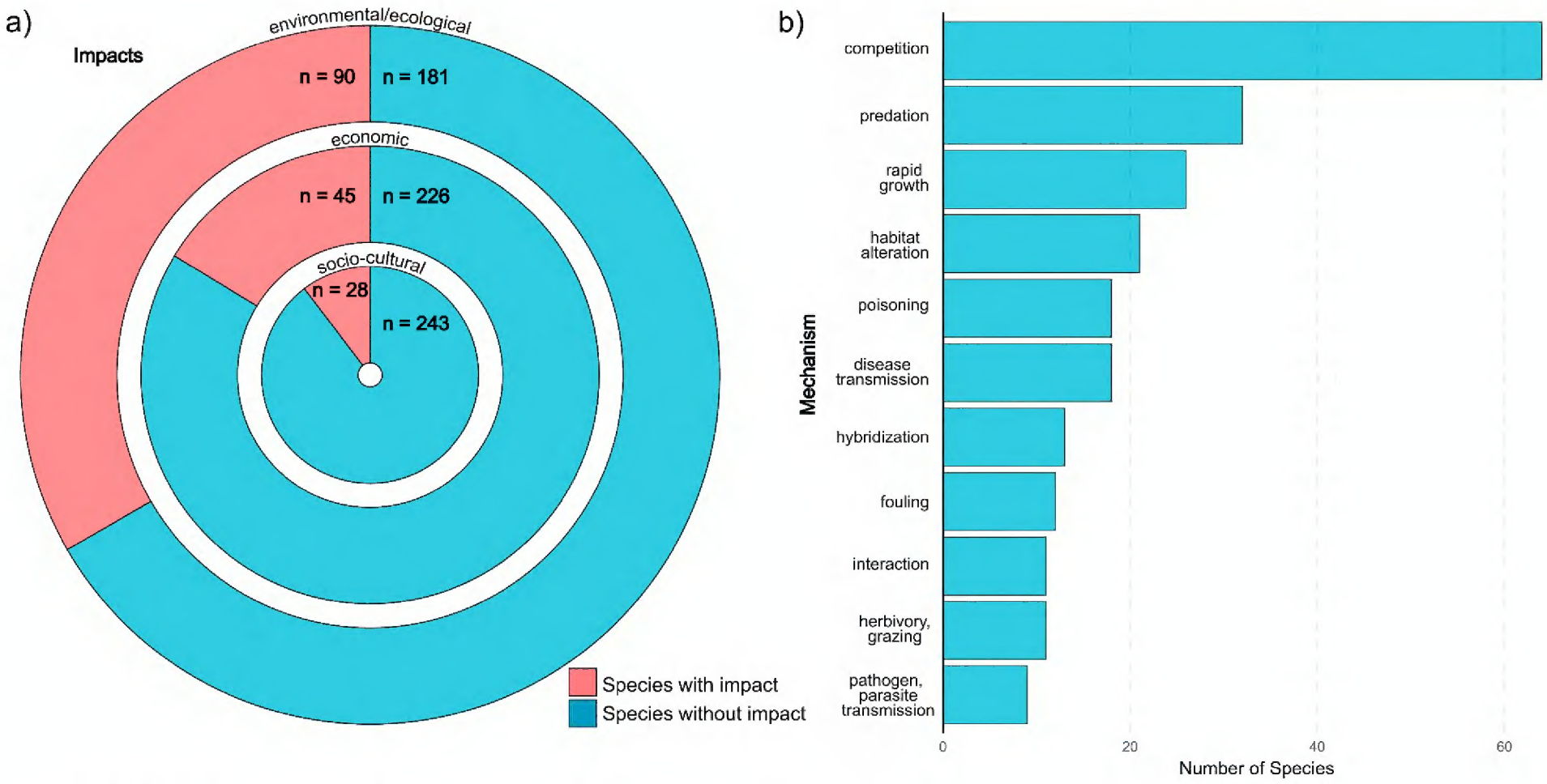

Figure 6. Doughnut plot indicating the species by (a) impacts and (b) impact mechanisms.

south-western coasts of Anatolia (Bilge et al. 2019) and of the Mediterranean Sea (Killi et al. 2020; Tarkan et al. 2021; Yapici 2021). Of the 62 established species in total: (i) under current climate conditions (BRA scores), 3 (4.8%) posed a very high risk of invasiveness, 25 (40.3%) a high risk, 33 (53.2%) a medium risk, and 1 (1.6%) a low risk; (ii) under predicted climate (change) conditions (BRA+CCA scores), 13 (21.0%) posed a very high risk of invasiveness, 25 (40.3%) a high risk, 23 (37.1%) a medium risk, and 1 (1.6%) a low risk (Fig. 7). Overall, the number of very high-risk species substantially increased under predictions of climate change conditions for Türkiye and the risk assessment areas therein.

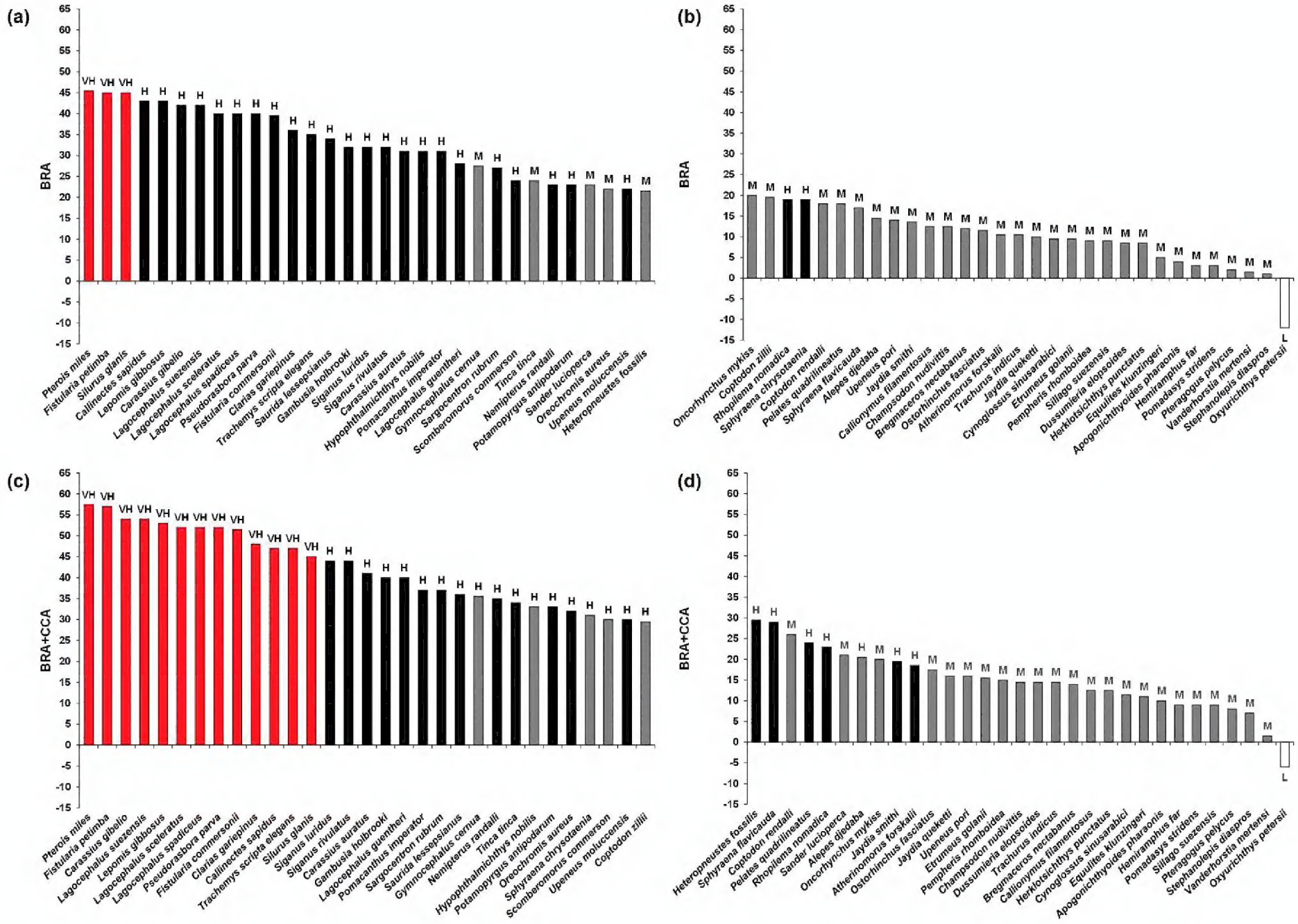

Figure 7. Risk outcome scores for 62 established species in Türkiye were screened with the Aquatic Species Invasiveness Screening Kit. (a) Basic Risk Assessment (BRA) scores for the first 31 species; (b) BRA + Climate Change Assessment (BRA+CCA) scores for the first 31 species; (c) BRA scores for the last 31 species; (d) BRA+CCA scores for the last 31 species. Red bars = very high-risk (VH) species (score ≥ 45); black bars = high-risk (H) species; gray bars = medium-risk (M) species; white bars = low-risk (L) species. Species-specific risk levels are based on the thresholds provided in Suppl. material 2.

Discussion

Türkiye has a long-standing tradition of research in the natural sciences, yet national efforts to address the threats posed by biological invasions remain limited (Şekercioğlu et al. 2011). This study has offered the first comprehensive national assessment of established species in Türkiye, identifying 271 species that may pose substantial threats to the country's biodiversity and social well-being. Our compilation points to clear biases, with the majority of the identified species occupying marine environments in contrast to the less-represented freshwater species (Butchart et al. 2010), with the same being true for certain taxonomic groups such as insects and fishes. Even more notable is the lack of information on these species' impacts, raising concerns about biological invasions being a silently growing threat, especially in the case of understudied taxonomic groups and regions. In relation to our hypotheses, we did not find support for (1) the expectation that the composition of established species would be dominated by terrestrial plants but with marine fishes being more prevalent, but (2) confirmed that regions with greater human activity tend to host more established species, while (3) less accessible or remote areas experience lower reporting of invasion. However, (4) the anticipated regional variation in impact severity was only partially supported, suggesting that impact may not scale directly with establishment density.

Compared to the 271 established species we identified here, the national list of non-native species published by Uludag et al. (2020) reported 872 species – a number much higher than in the present study. The main reason for this difference is that the latter list included all non-native species ever recorded in Türkiye, without confirming whether they are actually established or still present today. While our focus was on non-native species that are confirmed to be established, the 2020 list still represents an important resource for e.g. the screening of potentially established non-natives and thus to identify future threats. In that sense, even though the two lists serve different purposes, both are valuable for understanding and managing biological invasions in the country.

Taxonomic composition and biases

The taxonomic profile of Türkiye's established species is shaped by a mix of ecological, economic, and research-related factors. Our results show that Chordata, Mollusca, and Arthropoda are the most represented Phyla, with a clear dominance of marine species. This is not surprising given Türkiye's extensive coastline along the Black, Aegean, and Mediterranean seas, which provide a broad range of habitats. These areas are also under intense pressure from maritime traffic, aquaculture, and fisheries, all of which are known pathways for species introductions (Çinar et al. 2005). Such conditions help explain the high number of marine species in the national list.

The comparatively low numbers of terrestrial and freshwater species reflect a combination of factors. In the case of terrestrial plants, the lower figures may be somewhat misleading. Türkiye has a long history of plant introductions, especially for agriculture and horticulture, but not all introduced species establish successfully or are monitored closely (Uludag et al. 2017). For instance, the relatively small number of Tracheophyta in the dataset likely reflects gaps in research and reporting rather than true absence. Therefore, there is still a need for more detailed studies to fully understand the scale of non-native plant establishments. Comparison with recent national syntheses, such as Haubrock et al. (2025) for Germany and Soto et al. (2025) for the Iberian Peninsula, revealed that Türkiye's total number of established non-native species (n = 271) aligns well with expectations given its biogeographic position at the intersection of three major realms and its moderate research intensity. While Germany and Iberia host 1,962 and 1,273 established species respectively – reflecting their larger land areas and longer histories of invasion documentation – Türkiye's inventory demonstrates a comparable taxonomic breadth and similar dominance of marine and terrestrial taxa, corroborating consistent invasion patterns across southern and central Europe.

Freshwater species were even less represented, which may be explained by both ecological and research-related reasons. Many freshwater habitats in Türkiye, particularly those in regions of high human impact, have been degraded by pollution, habitat destruction, and hydrological changes (Pinarlik 2023). Such conditions can limit the success of new invasions (Rahel 2002). At the same time, freshwater environments in more remote areas might be under-surveyed, reflecting a lack of funding, institutional support, and research infrastructure in these regions. Therefore, both real ecological constraints and a lack of data have likely contributed to the observed pattern.

Regarding the role played by economic and industrial activities, marine ecosystems are heavily exploited for fisheries and aquaculture, which increases the

risk of species introductions and establishment (Nunes et al. 2014). On the other hand, certain terrestrial sectors, such as agriculture, may have stricter biosecurity protocols in place, which could explain the lower representation of some groups (Pimentel et al. 2005). However, these patterns may also reflect broader priorities, with more research and monitoring focused on economically important areas, leaving others underexplored.

Overall, these taxonomic and environmental biases underline the need for a more balanced research agenda. Without comprehensive assessments across all groups and environments, gaps in knowledge will persist, increasing the risk of unforeseen ecological and economic consequences. It is essential to strengthen research efforts, particularly in underrepresented areas like freshwater systems and terrestrial flora, to ensure that management and policy responses are based on a complete understanding of the country's non-native species landscape.

Spatial heterogeneity and regional variability

The distribution of non-native species across Türkiye displays marked spatial differences, with the highest numbers recorded in urban and especially coastal regions. This pattern largely reflects the role of human-mediated pathways, as areas with dense human populations, strong economies, and well-developed trade networks – such as Istanbul, Antalya, and Muğla – offer multiple routes for species introductions and establishment (Aikio et al. 2010). Key vectors in these regions include maritime transport, aquaculture, the ornamental plant and pet trades, and ballast water discharge, all of which are intensified by high volumes of trade and human activity. In contrast, areas with lower population densities and limited economic activity, such as more remote inland or mountainous regions, generally exhibit fewer invasions, which aligns with patterns reported globally (Essl et al. 2015).

The underlying reasons for these differences are likely multifaceted. Urban and coastal centers are hubs of international and domestic trade, dense infrastructure, and economic growth, which all contribute to the introduction and establishment of non-native species and where GBIF records are often concentrated (Hulme 2009). Increasingly, global trade, tourism, and financial networks are recognized as key human-mediated pathways for biological invasions, particularly in metropolitan settings (Seebens et al. 2021). In Türkiye, rapid urbanization and economic development have intensified these pathways, highlighting the critical role of customs controls, ballast water regulations, and cross-border enforcement in limiting new introductions. However, lax biosecurity enforcement, profit-driven trade in exotic species, and limited institutional capacity continue to undermine prevention efforts (Tarkan et al. 2024b). Financial incentives often favor short-term economic gains over long-term ecological health, placing additional pressure on regulatory systems that may lack political will or resources to implement stringent controls (Early et al. 2016). In many cases, regions with fewer resources and less institutional capacity also lack the funding, personnel, and infrastructure needed to monitor and manage non-native species effectively (Pyšek et al. 2020). Local communities, often burdened by more immediate socio-economic concerns, may have little opportunity to engage in biodiversity monitoring or early detection programs. This disparity likely contributes not only to lower actual introduction rates in remote regions but also to significant gaps in detection and reporting (Pyšek et al. 2010).

Importantly, areas where non-native species have already established may also serve as stepping stones for further spread within Türkiye. Once a species gains a foothold in a region, intentional or accidental translocations – often linked to activities such as recreational angling, aquaculture, and efforts to enhance local fisheries – can facilitate its movement to new areas (Tarkan et al. 2024a). These secondary introductions are often motivated by economic considerations or by the aim of improving local food security, but they can have far-reaching ecological consequences if left unchecked (Gaygusuz et al. 2015).

These observations highlight the need for management strategies that are tailored to the specific risks and realities of different regions. Urban and coastal areas with high introduction pressure require intensive monitoring and stricter biosecurity protocols, while less-affected regions would benefit from investments in local capacity, training, and public awareness. Furthermore, policy frameworks must account not only for initial introductions but also for the increasing risk of secondary spread within the country, which remains a significant challenge for invasive species management. Coordinated national efforts will be essential to mitigate the long-term impacts on Türkiye's biodiversity and ecosystems (Early et al. 2016).

Current and unknown impacts

A clear pattern emerging from our analysis is the high proportion of established non-native species for which no impacts have been reported. This likely reflects two main issues: first, many species have not yet been subject to formal impact assessment; second, some species – particularly those with restricted distributions or narrow ecological niches – may indeed have limited or negligible impacts. Initial impacts of biological invasions might seem benign or even positive, while being catastrophic in the long term (Soto et al. 2024a), potentially creating a lag in the reporting of impacts. However, our results also indicate biases in which environments and taxonomic groups are reported to have impacts. For instance, while marine species make up the largest portion of the dataset, the ratio of reported impacts to non-impacts is around 19%, whereas freshwater species show a notably higher ratio of 38%. Across taxonomic groups, Chordata has 14%, Arthropoda 23%, and Mollusca 18%, with Annelida (20%) and Tracheophyta (28%) also showing some level of recorded impacts. Many other groups have no reported impacts at all, underscoring a significant gap in current knowledge.

This pattern likely stems from a focus on species already recognized as problematic – such as large-bodied fishes or economically relevant invertebrates – while less conspicuous or poorly studied taxa remain overlooked. Such gaps are concerning because they can result in delayed responses to emerging threats, ultimately increasing biodiversity loss and the economic costs of management. For Türkiye, with its rich biodiversity and reliance on ecosystems that are vulnerable to invasive species (Tarkan et al. 2024b), the absence of robust impact data represents a serious blind spot. Closing this gap requires systematic and ongoing assessments, particularly targeting under-studied groups and habitats. Expanding monitoring and research to reflect the full spectrum of Türkiye's ecosystems will be crucial for strengthening biosecurity and ensuring timely, evidence-based management actions.

Invasiveness risk

The finding that more than 50% of established species in Türkiye, among those for which screening data are available, pose a high to very high risk of invasiveness, increasing to over 60% under predicted future climate (change) conditions, is concerning. As a representative subset of the whole list of 271 established species in Türkiye, a similar outcome may be expected should the remaining species be eventually screened for their invasiveness. The limited number of species screened so far is likely due to the unavailability of data for terrestrial species, as the relevant decision support tools for animals (the Terrestrial Animal Species Invasiveness Screening Kit, TAS-ISK: Vilizzi et al. 2022b) and plants (the Terrestrial Plant Species Invasiveness Screening Kit, TPS-ISK: Vilizzi et al. 2024) – have only recently been developed (see also Vilizzi et al. 2025). Given the availability of our up-to-date list of established species for Türkiye, future studies should not only screen the other aquatic non-native species, but also terrestrial non-native animals and plants. This would provide a comprehensive database of information based on which local legislation for the monitoring, control, containment, and, if at all feasible, eradication of any established species in Türkiye could be gauged accordingly. Moreover, given that nearly two-thirds of the screened species fall into the high to very high risk categories under future climate conditions indicates the need to establish a prioritization framework for their management. This could help allocate limited conservation and management resources more effectively by targeting species and regions at the greatest risk. Such a framework should consider both the risk outcome scores (BRA and BRA+CCA) and ecological or economic impact potential, especially for species expected to escalate in risk due to climate change. However, we underline the importance of prioritization as critical biosecurity component to guide early detection and rapid response measures.

Conclusion

Türkiye's strategic location at the intersection of Europe, Asia, and the Middle East makes it a central hub for the spread of non-native species. Türkiye shares many non-native species with neighboring European and Mediterranean countries as documented in regional inventories. Our findings also suggest that it not only receives species from other regions but may also act as a source of invasions to nearby countries. The observed spatial heterogeneity and regional variability highlight the need for tailored management strategies that consider both local and international contexts. Moving forward, addressing the identified biases, expanding research into underrepresented groups, and strengthening biosecurity measures will be critical to preventing future invasions. A coordinated approach, built on the insights from this comprehensive list, is essential for protecting Türkiye's biodiversity and ensuring the sustainability of its ecosystems.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Experts responsible for taxonomic verification of non-native species in Türkiye and the corresponding numbers of taxa before and after expert verification

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Supplementary material 2

Risk ranks from the Aquatic Species Invasiveness Screening Kit for 62 established species in Türkiye

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Data type: docx

Explanation note: For each species, the following information is provided: risk assessment area; calibrated threshold to distinguish between medium-risk and high-risk species (with low-risk species distinguished by a score < 1); BRA (Basic Risk Assessment) and BRA+CCA (BRA + Climate Change Assessment) scores with corresponding risk ranks (L = Low; M = Medium; H = High; VH = Very high, based on an ad hoc very high-risk threshold ≥ 45); reference study.

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